

Shotcrete Design Guidelines

Design guidelines to avoid, minimise and improve the appearance of shotcrete





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Foreword

This is the third guideline published under the Beyond the Pavement initiative. It accompanies *Bridge Aesthetics* and *Noise Wall Design Guidelines* and addresses the issue of the visual impact of shotcrete.

While shotcrete is a useful and cost effective means of stabilising or supporting cuttings it is particularly unsightly and it would be better if the need for its use could be avoided. This document recommends that the best way to do this is to consider the ramifications of the vertical and horizontal alignment very early on in the route selection and concept design stages.

However this is a practical document and it is recognised that in certain situations there are sound reasons for its use. For these cases a number of measures are provided to minimise its extent and improve its appearance all with the aim to make the application as unobtrusive as possible.

To achieve these goals it is important that a balanced approach be adopted mindful of the practical benefits of shotcrete as well as the potential visual impacts.

I commend this document to development and project managers and their geotechnical and urban design advisors.



Paul Forward

Chief Executive

June 2005

Introduction

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Introduction

The use of shotcrete has recently come under scrutiny. Although it is cost effective and useful, when used in its natural, untreated state, it is visually intrusive, particularly in highly sensitive urban or rural areas.

Due to its poor visual qualities there is often a call to restrict its use. However, this is not possible as it is a valuable engineering technique, useful for stabilising and providing structural support for problematic slopes.

This has unnecessarily caused a difference of opinion within road design teams because if considered at the outset, in the route selection and concept design stages, designers and engineers can agree on a common goal to avoid the need for slope stabilisation for visual as well as cost and maintenance reasons.

Therefore this document addresses the need to consider unstable slopes early on in the road development process and sets down a strategy and recommendations to avoid or minimise the eventual need for shotcrete. However it also recognises that there will be circumstances where shotcrete is inevitably required and addresses the real practical problem of what is an acceptable appearance.

Introduction

Shotcrete is nearly 100 years old as a construction technique yet it can still generate considerable debate and criticism. The following comments were raised at an RTA batter design workshop:

- "Shotcrete is a maintenance problem caused by poor design."
- "Shotcrete is not so much about poor design, as no design."
- "Its need can be generated by pressures to protect habitat, yet habitat quickly recovers."
- "If we don't get the land we've lost the battle."
- "There are no good examples of shotcrete visually."
- "The good examples you don't see because they are unobtrusive."
- "Shotcrete is not something that is planned."
- "Shotcrete is not a surprise... we are aware that it will be needed and an allowance for an application is usually made, however we don't know where it will be needed."
- "A greater degree of geotechnical knowledge is needed."
- "The only real geotechnical knowledge comes from complete excavation."

August 2003

Introduction

Ideally, if space were unlimited and unstable slopes able to be graded out, shotcrete could be avoided on our road corridors. This would be desirable because stabilised slopes are an expensive ongoing maintenance burden; shotcrete can fail, it adds to the extent of impermeable surfacing in the road corridor; it precludes vegetation cover and when untreated and used in large expanses is unsightly.

Yet in reality, there are many factors that can result in the use of shotcrete. For example space is limited, as is money, and steep cuttings are often unavoidable. Also geotechnical knowledge is, by its nature, not perfect until the cutting is exposed and shotcrete, although not initially required, may become essential. Furthermore, in the case of existing roads, shotcrete may be the only technique available to road maintenance teams.

Consequently, for many reasons, shotcrete is a fairly common element of our roads. However, although its use is often planned by geotechnical advisors, its appearance or visual impact is rarely addressed in the concept or detail design stages of a project's development.

A more balanced approach to the treatment of shotcrete is needed which addresses appearance as well as function.

Introduction



Shotcrete application.



A crumbly shale band, which if higher up the cutting would need to be stabilised.

1.1 The use of shotcrete

Very simply shotcrete is the term used for spraying concrete and mortar onto a surface at high velocity.

It was invented in 1907 and patented as Gunitite. Its popularity grew rapidly from 1912 to the 1930s and during this time the term shotcrete was coined following the introduction of aggregate mixtures.

During the 1970s silica fume was introduced to shotcrete and it became viable as an underground mining support.

Today shotcrete has become a very useful material due to its high strength, durability, low permeability, good bond, limitless shape possibilities and ease of handling in areas of difficult access. It also requires no formwork, is highly cost effective and is particularly useful where land space is limited.

Shotcrete is a treatment applied to batter surfaces, usually for one of two reasons:

1. To protect a surface which, left untreated, would fret and erode (or is already doing so). Such surfaces may be localised or comprise anything up to the entire batter, depending on the circumstances.
2. To provide structural support for otherwise sound rock which is being undermined by erosion or which is unstable (due to defect orientations or degree of fracturing).

The two functions may be combined in many cases.

The circumstances of its use may arise either as part of the original construction or as remediation of existing batters. The distinction is important. New work should allow substantial control over geotechnical design, and hence pre-construction decisions about batter slopes and how they will be stabilised and maintained. Treatment should be planned and preventative, rather than remedial, although some surprises may occur. For existing slopes, you have what you have and the treatment is almost always remedial. While the possible options may be similar, the constraints on their use (including costs) are different.

There should always be a clear purpose for the use of any engineering measure and shotcrete is no exception. It must be understood in terms of its intended function(s) and comparisons made with alternatives which could replace it.

Introduction

It is not practical to dismiss the use of shotcrete due to its appearance. The science of rock durability is very complex and there are few experts in Australia who could predict with a great degree of accuracy the durability of all types of rock after exposure. Judicious use of shotcrete to ensure the stability of the batter (or slope) and the safety of road users is inevitable when considering the extent of our road network.

Nevertheless shotcrete is sometimes used in excess and applied when not always needed. Project managers and their teams need to apply control to the applications so that it is applied with precision and mindful of visual impacts.

Introduction



Architectural roadside shotcrete applications in California.
www.boulderscape.com



Shotcrete application used to stabilise the cutting at Oak Flats interchange near Wollongong, is highly intrusive in the scenic pastoral landscape of the foothills of the Illawarra Escarpment. (This application was not planned and arose due to the construction technique of bulk blasting rather than pre splitting. The photograph on the right illustrates the outcome if pre-splitting had been adopted).



Shotcrete application, Princes Highway south of Wollongong.



Shotcrete application used to stabilise the top bench of a cutting on the Yelgun to Chinderah section of the Pacific Highway Upgrade. This application arose due to the need to deepen the cutting to balance additional fill requirements due to the discovery of soft soils. (Additional land was not available due to its habitat status.)

1.2 The appearance of shotcrete

Research into the subject of shotcrete appearance prompted this response from a member of the American Shotcrete Association.

“Could you please elaborate on what you mean by “shotcrete appearance”. Shotcrete can vary in appearance from very rough in the natural as-shot (unfinished) condition, to moderately rough (although plane) in the “rodded” condition, to as smooth as cast-in-place concrete with appropriate finishing. Very pleasing appearances can be produced with architectural shotcretes with a wide range of different types of finished surfaces.”

It seems that in the USA, unlike in NSW, it may be unusual to leave shotcrete in its raw state.

Clearly, shotcrete has no particular appearance and like any other structure needs to be designed. Yet unlike many other structures; its raw state is particularly unsightly and there is little or no functional benefit to justify improving its appearance.

More specifically when used in large expanses:

- It can cover up a natural rock or rocky finish.
- It generally precludes the establishment of vegetation.

Also in its raw ‘as shot’ state

- It is formless and has no structured appearance unlike a mesh system, concrete wall or gabion wall.
- Its ‘porridgey’ texture rarely complements natural surfaces.
- It is generally monochromatic its blandness particularly highlighted in highly valued landscapes.

The photographs at left and following illustrate just a few examples of the intrusive nature of shotcrete.

Introduction



Shotcrete application used to stabilise the cutting around the curtilage of the bridge over the Pacific Highway at Environ Road (Yelgun to Chinderah section, DCM contract). The scale of the application and its colour variation are visually intrusive and do not provide a good setting for the bridge.



Even where the colour match is relatively good on this project in the Blue Mountains, its monochromatic and amorphous nature is in poor contrast with the underlying rock. A key question here is why shotcrete was used on the flatter sections of the cutting at all. (A later decision was taken to cover this application with sandstone filled rock mattresses.)



Shotcrete lined drainage channels, Pacific Highway. The wide channels (to avoid scouring) are intrusive adjacent to the road corridor and the overspray will deter adjacent vegetation establishment.



Black shotcrete application along seam in sandstone on the F3. The colour match, overspray and texture are in poor contrast with the particularly beautiful sandstone.



The M2 was one of the RTA's earliest BOOT projects. Few outcomes were defined regarding finished surfaces to cutting and walls and the shotcrete applications consequently proved most cost effective to the road consortium. The shotcrete is particularly ugly exacerbated by the scale of the application.



In this example at Mount Ousley on the F1 the black colouration fits better with the context.



M2.



A good appearance has clearly not been achieved with this shotcrete application over a small slippage at Wollongong Station.

Strategy

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The best strategy in dealing with shotcrete in terms of cost, safety, appearance and environment, is to adopt the hierarchy of:

2.1 Avoidance

Avoidance refers to the objective of avoiding or minimising the need for any form of slope stabilisation right from the start of the road development process.

2.2 Minimisation

Minimisation refers to the objective of minimising the extent and visibility of shotcrete.

2.3 Improve appearance

Improve appearance refers to the objective of designing the finish of the shotcrete application so that it is as unobtrusive as possible.

The following section sets down objectives and principles to guide the adoption of this strategy.

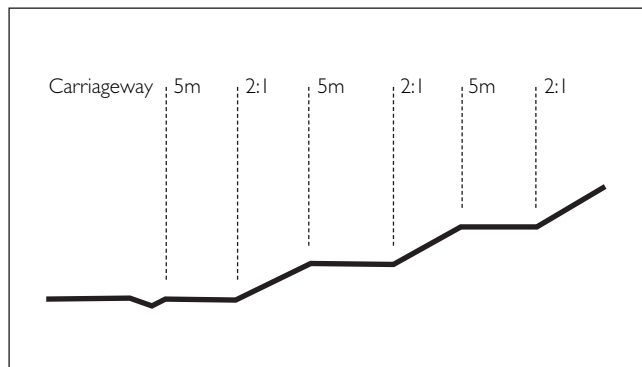
The aim is to achieve a more balanced approach to the use of shotcrete so that design quality and road user enjoyment is considered as well as cost and safety.

Avoiding or minimising the need for shotcrete

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Avoiding the need for shotcrete



A stable and easy to vegetate cutting profile.



2(H):1(V) cutting on Hume Highway.

3.1 Objective

The need for the use of shotcrete or any other batter stabilisation technique should be avoided. Besides being particularly unsightly, relative to an untreated safe slope shotcrete is costly and high maintenance. It is better to have designed the cutting so that stabilisation is not needed.

The best time to avoid or reduce the need for shotcrete is in the route selection and refinement process. The best way to avoid the need for shotcrete is to allocate sufficient space for the road and the cuttings.

Liaison with geotechnical experts in the route selection stages will assist in defining the space needed for the road corridor by advising on appropriate cutting slopes.

3.2 Principles

3.2.1 Obtain sufficient land

The need for shotcrete can be eliminated through purchase of sufficient land so that batters can be laid back to a stable grade. Where adjacent land is highly valuable or threatened habitat, discussions should be held with stakeholders to consider the relative merits of the land needed versus the costs (financial and aesthetic) of the shotcrete application.

3.2.2 Avoid over steep cutting faces

The need for batter treatment arises when cutting faces are over steep for the combination of rock types, fracturing and weathering patterns intersected.

Ensure that the stability and treatment consequences of steepening cutting faces is given appropriate consideration at the route selection and concept design stages.

Where there is limited geotechnical information it is preferable to nominate flatter rather than steeper batters in an EIS.

Design for optimal not maximum gradients, then if there is a change in gradient or slope stability, shotcrete may still not be necessary.

In most situations, slopes flatter than 2(H):1(V) with 5m benches and setbacks from carriageways will provide a stable cutting as well as allow space for vegetation to establish.

Avoiding the need for shotcrete



Two cuttings on Hume Highway, one with a setback and limited shotcrete (left), the other adjacent to the road requiring significant shotcrete coverage.



Mesh netting Hume Highway (above) and F3 (below).



Locally won rock used as a gravity wall retaining structure and alternative to shotcrete, (bridge over the Woronora River).



Rock Mattresses and stone, stabilising cutting on Hume Highway near Mittagong.

3.2.3 Provide space for cuttings

Obtaining sufficient space between the road and rock cutting is by far the best way to avoid the need for shotcrete. Every metre gained has a significant impact on the risks posed by an unstable cutting. It also allows planting to develop to help catch debris, improve the appearance of the road corridor and break up the expanse of concrete.

3.2.4 Explore other sources of fill if required

In occasional situations cuttings are deepened to balance additional fill requirements by steepening cutting faces rather than by widening the cutting footprint. In these circumstances consider borrowing material from other locations.

3.2.5 Explore alternative stabilisation techniques

Where potential shotcrete stabilisation needs are identified explore alternative solutions such as:

- Reduce face heights and steepen slopes to reduce erosion.
- Shotcrete application on the bench top only, to minimise water penetration and ongoing erosion.
- Rock bolting (where possible rock bolt heads should not be covered with shotcrete).
- Mesh netting or use of bolted rock mesh.
- Fencing at key locations on the benches and base of slopes to catch loose material.
- Soft fall areas at the base of slopes to contain loose material.
- Locally won rock gravity walls (eg Woronora bridge project).
- Retaining walls or precast panels over stabilised cuttings, to be considered in urban areas with high land value and high quality finishes needed.
- Slopes stabilised by rock mattresses or stone.

Avoiding the need for shotcrete



Untreated cutting on Hume Highway.



Concrete panel covering pile retaining wall and shotcrete on the Liverpool to Parramatta Transitway.

3.2.6 Be judicious in the use of shotcrete

Consider the costs and benefits of the 'do nothing' option. If there is sufficient space, allowing the slope to weather and erode safely may be the best option in the long run.

3.2.7 Specify pre splitting

Specify excavation methods that minimise the risk of creating unstable slopes (eg Oak Flats interchange where rock was ripped rather than pre split).

Prepare specifications and manage contracts such that the risk of blasting damage to pre-split faces is minimised (refer Earthworks Spec. R44, Clause 4.5.2).

3.2.8 Consider covering shotcrete

In certain highly sensitive rural and urban situations and around bridges the EIS (or Scope of Works in a D&C situation) should specify that there should be no visible shotcrete applications.

Minimising the extent of shotcrete

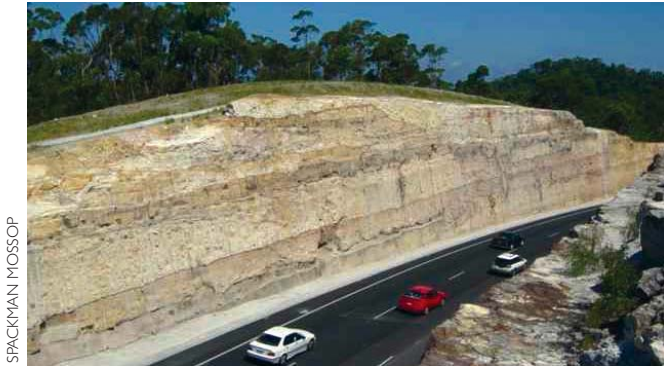
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Minimising the extent of shotcrete

4.1 Objective

If the use of shotcrete cannot be avoided then all efforts should be undertaken to minimise its extent or screen it.



Shotcrete application carefully minimised on the F3.

Minimising the extent of shotcrete



Two cuttings with similar stability problems. Precision design and progressive stabilisation can minimise the extent of shotcrete (Hume Highway).



Shotcrete applications extend neatly to the edge of a change in the rock surface and coloured to match existing rock can look quite unobtrusive and visually acceptable. (Southern Freeway FI.)

4.2 Principles

4.2.1 Precision design

Aesthetically it is far better (and more cost effective) to apply shotcrete precisely to unstable sections of cuttings than to apply a blanket covering.

In order to achieve this the shotcrete application should be planned and designed in advance so as to minimise visual impact as well as stabilise the slope. This planning need not be time consuming if the right expertise is employed and could be based upon photographs of the emerging cutting.

4.2.2 Progressive stabilisation

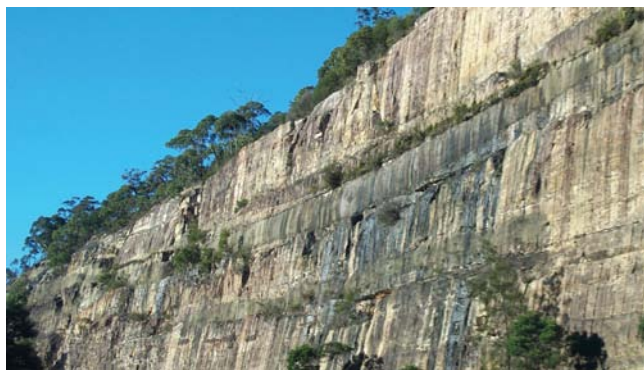
Stabilisation treatments (including shotcrete) should be applied progressively with excavation rather than left to the end.

This tends to minimise usage which is a cost saving and satisfies both geotechnical and urban design objectives. (R44, Clause 4.2.1 has a hold point at each bench level for this purpose.)

4.2.3 Relationship with surrounding rock

Finish or extend the application of shotcrete up to distinct edges, natural joints or changes in the face of the cutting.

Minimising the extent of shotcrete



Shotcrete application along seams in sandstone on the F3. The colour match and precise nature of the application coupled with natural staining have almost rendered the shotcrete unnoticeable.



Planting successfully spilling over and obscuring shotcrete and walling on Mount Ousley Drive.



A dark coloured shotcrete covers this coal seam on the F3 near Newcastle. The shotcrete is quite unobtrusive due to its dark colour however where planting is in front of the application, although still partially visible, the shotcrete is unnoticeable to the majority of road users.

4.2.4 Masking

Shotcrete should be controlled and applied only where required and masked off for other areas, for example in soft rock seams.

A neat sharp edge, especially if it coincides with a change in the rock texture or a fracture line, is generally more appropriate than bleeding the shotcrete out or allowing overspray. However it should be accepted that feathering the shotcrete may be required in order to achieve a good bond with the rock.

4.2.5 Screening

Planting should be used to help screen the shotcrete application.

Improving the appearance of shotcrete

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Improving the appearance of shotcrete



Where a shotcrete stabilised slope is 'wall type' in appearance, there is no need to colour it to match the local rock. A plain concrete finish would be sufficient.



A dark earthy red/grey/brown colour helps recede the shotcrete into the rock of the lower half of the cutting on the Pacific Highway near Taree.



A sandstone yellow colour renders this application on the F1 unobtrusive.



Excellent colour match on this cutting on the Hume Highway renders the shotcrete practically invisible. Colour matching works best where the rock is monochromatic.

5.1 Objective

All shotcrete applications visible from the road or surrounding public areas must be designed so that the application is as unobtrusive as possible in the local context.

Consider the production of trial sections to assess appearance before final shotcrete applications are commenced.

5.2 Principles

5.2.1 Colour

The colour of the shotcrete can either be one of the most successful ways to minimise its intrusiveness or conversely the best way to make it stand out starkly against the rocky or vegetated background. Colour must be carefully considered and inspired by the natural local rock.

Achieving colour matches with adjacent rock; creating a consistent colour; and delivering a satisfactory colour outcome is extremely difficult. There are no hard and fast rules however the following principles should be considered:

- With many exceptions darker shotcrete tends to be less intrusive than light shotcrete but avoid dark shotcrete on light rock or light shotcrete on dark rock.
- It is important to get a feel for the overall colour and tone effect of the cutting. Picking out one particular colour and tone can be unsuccessful if it doesn't represent the overall impression. Estimate an average colour of the cutting and apply that colour to the concrete.
- With monochromatic rock, coloured concrete can be a very successful way to hide the application.
- If the shotcrete is covering all exposed rock then there is little point in aiming to achieve a colour match, better to select an unobtrusive colour that fits the local context.
- Attempting to achieve colour blends in shotcrete is rarely successful.
- If the shotcrete application is formed into a formal geometric (wall) shape then colouring concrete to achieve a natural look is not appropriate.
- Time always changes the colour of both rock and shotcrete, through water staining, air particles, exhaust emissions, vegetation growth and weathering.

Improving the appearance of shotcrete



A natural reddish brown colour applied to this application on the Bangor bypass helps in making the shotcrete as unobtrusive as possible.



Rock sculpting (Rock & Water Pty Ltd). Paint can help blend the shotcrete with the rock but care must be taken that it does not appear artificial.



Painting

In some situations a painted finish is possible, to match up with the surrounding rock.

The context of the cutting and the local landscape should be carefully considered as painting can often draw attention to the shotcrete and can sometimes look false. Painting also weathers and loses its effect.

Improving the appearance of shotcrete



The natural jointing of rock often creates a texture which is angular and planar rather than amorphous.

5.2.2 Texture and sculpting

The texture of the shotcrete is almost as important as colour and has been often overlooked in shotcrete applications.

Rock is often characterised by a collection of planar surfaces which is quite different to the granular amorphous finish of shotcrete.

The ways in which a texture can be applied to shotcrete needs to be explored however the following are some possibilities.

- Trowelling the shotcrete to a smooth but irregular pattern to match natural planes in rock.
- Forming the shotcrete to a smooth but formal shape to create the impression of a purposeful element such as a retaining wall.
- Stamping the shotcrete with timber boards or moulds.
- Leaving an exposed aggregate finish to provide natural colour and some texture.
- Rock sculpting.

When shotcrete is applied in small scale and prominent situations, consider sculpting the surface of the shotcrete so that its appearance is similar to the surrounding rock.

The success of this technique is heavily dependant on the skill of the artisan and the context of the area. Great care needs to be taken to avoid an artificial or kitsch appearance.



MCINERNEY

A formal element in the landscape can be more acceptable than a formless finish such as untreated shotcrete.



A rock type finish on the southern approaches to the Spit Bridge, Sydney.



Roadside shotcrete application sculpted into a natural rock finish, California. At this scale sculpting shotcrete needs to be carried out with great skill or it could look very artificial. (www.boulderscape.com)

Improving the appearance of shotcrete



Stone pitching used to line a drainage channel in a rest area on the Hume Highway at Lake George.



Stone pitching used around bridge abutment, Bangor Bypass.

5.2.3 Stone pitching

In some sensitive situations stone pitching may be appropriate. It obscures the underlying concrete and provides a natural rock finish.

Improving the appearance of shotcrete



Rock filled mattresses placed over shotcrete application, Great Western Highway at Linden.



Dark grey shotcrete framed with planting and gabions on the portals to the tunnel on the Yelgun to Chinderah Pacific Highway Upgrade.

5.2.4 Rock mattresses

An expensive but visually satisfactory way to cover shotcrete on shallower cuttings is through the placement of gabion mattresses filled with locally won stone. On shallow slopes it should be considered as an alternative to shotcrete.

5.2.5 Framing

Visually containing the shotcrete coverage through planting and gabions or concrete retaining walls can also be successful.

However the need to control the shotcrete application in terms of colour, texture and consistency is still important.

Design process



Design process

The guidelines in this document can be summarised in the following 10 steps, which apply from route selection right through to detail design.

Design process

SPACE FOR ROAD CORRIDOR	1	Consider impact of road alignment on cuttings and their stability. Ensure adequate space for road corridor:
SET BACK	2	Maximise set back distance of base of cutting from carriageway.
LAY BACK	3	Lay back cuttings to a maximum steepness of 2(H):1 (V).
ALTERNATIVES	4	Consider alternative stabilisation treatments.
PRECISION	5	Analyse cutting faces and design applications so that is restricted only to the seams, faults and areas that require stabilisation.
PROGRESSIVE STABILISATION	6	Ensure treatment is applied as early after the face is exposed as possible.
COVER	7	Consider covering over shotcrete in sensitive areas.
COLOUR	8	Consider the colour and brightness of the concrete. Specify the production of trial sections, ensure consistency.
FORM AND TEXTURE	9	Consider the form of the application and the texture of the finish. Specify the production of trial sections.
LANDSCAPE	10	Consider planting and seeding as screening.

Appendix:

The geotechnical aspects of shotcrete use

The geotechnical aspects of shotcrete use

Shotcrete is not an end in itself. It is a treatment applied to batter surfaces, usually for one of two reasons:

1. To protect a surface which, left untreated, would fret and erode (or is already doing so). Such surfaces may be localised or comprise anything up to the entire batter, depending on the circumstances.
2. To provide structural support for otherwise sound rock which is being undermined by erosion or which is kinematically unstable (due to defect orientations or degree of fracturing).

The two functions may be combined in many cases.

The circumstances of its use may arise either as part of the original construction or as remediation of existing batters. The distinction is important. New work should allow substantial control over geotechnical design, and hence pre-construction decisions about batter slopes and how they will be stabilised and maintained. Treatment should be planned and preventative, rather than remedial, although some surprises may occur. For existing slopes, you have what you have and the treatment is almost always remedial. While the possible options may be similar, the constraints on their use (including costs) are different.

The technical basis for using shotcrete

There should always be a clear purpose for the use of any engineering measure and shotcrete is no exception. It must be understood in terms of its intended function(s) and comparisons made with alternatives which could replace it.

Surface protection

This will normally be to cover erodible soils, or rock which is erodible or unsound eg a fretting surface. The batter would normally be steep (ie 1:1 or steeper). Flatter batters would usually be better treated by other methods. The surface to be treated may be a well-defined strip (or strips) with different properties from the surrounding rock (eg shear zones as at Jugiong, shale lenses in sandstone), or it may form a large part, even all, of the batter (eg shales, siltstones, tuffs, some sandstones). Adverse consequences from the erosion of the surface are undercutting of more competent areas of rock and the supply of the eroded material into the stormwater drainage. In some cases, unsound rock is also an acid sulphate problem.

Differential erosion of the batter gives rise to stability problems which will normally get worse with time. More uniform erosion or fretting is normally less of a threat to stability (unless the batter was too steep to begin with) but produces pollution problems which may not be acceptable.

The need for surface protection should normally be capable of anticipation at the design stage, although occasionally a rock will show a delayed response to exposure. In some cases, quite detailed assessments can be made. In others, the circumstances requiring protection can be understood and anticipated, but the detail of specific locations will have to wait until the batter is exposed. This will almost always be the case where there is complex geology. Commonly, the situation is intermediate between these extremes.

Structural support

Shotcrete in this application will form part of a structural system, intended to support the batter, which will often include other components (eg chainwire or steel mesh, rock bolts, dowels or rock anchors). The shotcrete may be fibre reinforced. The key difference is that the shotcrete will be required to resist, or transfer, loads. It may also have an essential surface protection function in conjunction with the structural function (eg in soil nailing). Fibre reinforced shotcrete (FRSC) is an essential component in most modern tunnel support systems.

Shotcrete may also be applied to rock surfaces to prevent sound rock material falling out, particularly where it may land directly in traffic (eg above tunnel portals and where steep cuttings are constructed next to narrow shoulders).

Again, the need for this should be capable of being anticipated, with varying degrees of precision as far as locations are concerned.

Construction damage

Large scale uses of shotcrete may result due to the batter condition being different from the condition expected before tender. This often has to do with damage caused by construction processes, particularly blasting. Less commonly, design changes are forced by stability issues which were not recognised before construction. In some cases, delay in applying stabilisation measures has also necessitated an increase in quantities.

Typical problems are:

- Fracturing and loosening of a face due to poor blasting practice (has happened even where the batters are pre-split) usually the result of pressure to keep excavation costs down, or to keep production rates up. On a big job, the latter may make the subsequent extra treatment economically viable for the contractor, even if he has to pay for it.
- Damage to the upper part (usually 1-1.5 m) of the batter – typically “lifted” by blasting, combined with a need to maintain minimum bench widths for access purposes.
- Delay in applying treatment, allowing erosion of weaker materials and opening of fractures due to stress relief, weather effects and vibration etc from excavation deeper in the cut.

Design changes

Usually batter steepening, often to accommodate a need for extra width at formation level (for paving, commonly) or a realisation that a batter has been designed over-steep, or is not performing as anticipated. Better design practice can alleviate this, to a point. However, many of the worst examples of extensive, ugly (and what should have been unnecessary) shotcrete applications come from this cause. Once it has happened, it is difficult to avoid the consequences.

There are also cases where over steep batters have been designed before construction and with the intention of stabilising them, due to footprint restrictions.

Appendix:

The geotechnical aspects of shotcrete use

Contractual aspects

Effective contract administration requires that shotcrete quantities be anticipated and included in the schedule of rates. There would normally be a fixed quantity and then an additional provisional quantity to cover changes which are decided once the batters are exposed. Good practice would set these so that all of the fixed quantity and part of the provisional quantity is used.

Some thought also needs to be given to the unit of payment (m^2 or m^3). There are arguments for and against both of these – which is better depends on the specifics of the job and the circumstances of application.

Some of the recommended construction requirements have been part of the earthworks spec for many years (eg pre-splitting or line drilling for batters 1:1 or steeper which require blasting for excavation). Others have been introduced in the most recent revision (eg requirements for progressive installation of stabilisation treatments).

It is again emphasised that shotcrete use should be capable of anticipation. That depends firstly on there being enough information to allow a reasonably accurate geotechnical model to be formed, secondly on that modelling actually being done and thirdly on its implications being properly incorporated into the design and specification. Unanticipated shotcrete use is far more commonly due to the second and especially the third of these.

What needs to be avoided is a philosophy which says:

- Minimise the footprint by keeping batters as steep as possible. “We can always engineer our way through any difficulties.”
- Only consider defect-related mechanisms in determining batters and prospective treatments.
- Do not consider long term performance and maintenance requirements.
- Defer treatment as far as possible during the contract (or worse, do it separately after completion) to avoid any delay to earthworks construction.

Remediation of existing batters

The principles in this are similar to those involving new construction, but the circumstances are different. Remediation always involves a batter which is showing evidence of problems, and the purpose is to stop them getting worse (and usually, to improve things). However, because the face to be treated is visible and the treatment is necessarily closely specified, quantities and locations can be detailed, as can any finish requirements.

The downside is that work is usually carried out under traffic and there may be an urgency associated with public safety. OH&S requirements may also limit the use of alternatives and of finishing treatments. A further constraint is that regrading may be difficult or impossible, forcing the design solution towards stabilisation measures.





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